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Artisanal stone-mining impacts on leaf microstructures and biochemical parameters of some plants at Eziani, Nsukka, Nigeria

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Abstract

Plants are determinant of air quality and are useful in mitigating air pollution and biomonitoring of the pollution stresses. Present study assessed the effect of stone-mining dust accumulation on foliar parameters and air pollution tolerance index (APTI) of five plants (*Annona senegalensis, Bridelia ferruginea, Ficus capensis, Nauclea latifolia* and *Protea madiensis*) commonly growing around an artisanal stone-mining site at Eziani Nsukka and Botanical garden of the University of Nigeria, Nsukka, the control. Dust load was estimated gravimetrically. The foliar analysis carried out on the epidermises was obtained by clearing method and studied under microscope and all photomicrographs were taken with Moticam camera 2.0 attached to the microscope. Biochemical parameters and APTI were determined following standard methods. Dust accumulated on polluted plant leaves was high and resulted in distortion and deformation of the epidermal and guard cells. The cells appeared stretched and broken compared to the control plants. Quantitati ve stomatal indices such as length, width, size and density were also significantly affected by dust pollution. Polluted plants showed increase in ascorbic acid, reduction in pH values, relative water content and total chlorophyll content, and produced low tolerance index than the controls. Highest and lowest APTI were found in *A. senegalensis* and *B. ferruginea*. At polluted site, *A. senegalensis* had APTI (17.14 ± 0.24) and *B. ferruginea* had (11.38 ± 0.07) which differed significantly from the APTI of *A. senegalensis* (18.92 ± 0.24) and *B. ferruginea* (13.49 ±0.28) at the control site. *A. senegalensis* was the most tolerant to air pollution while other plants were intermediate tolerant plants. The abnormalities in artisanal stone-mining plants may be due to prolonged exposure to dust. However, ability of the plants to tolerate air pollution makes them potential good environmental cleaners and as such, are recommended as choice plants around stone-mining and dust-polluted sites for safer environments and better health of both miners and the inhabitants.

Keywords: Artisanal**,** stone-mining, dust pollution, foliar parameters, biochemicals properties, leaf microstructures.

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INTRODUCTION

Ambient air is the most expected resources for sustaining and promoting life, good health and ontogeny but has become highly polluted due to emission of various substances and energy into the air, which result in unfavorable alteration of the natural ecosystem. Air pollutants are the contaminants emitted directly to the atmosphere or formed from reactions generated chemically, mechanically, and through combustion. Pollutants may be gases or suspended particulates like; CO, SO_x, NO_x, soot, toxic metals, coal, dust, smoke, smog, radiative isotopes, mercury, volatile organic compound, which arose as an outcome of increased population, technological revolution, industrialization, urbanization and anthropogenic speedy exploitation of natural resources (Agbaire and Esiefarienrhe, 2009; Sahu *et al.,* 2020). Particulate matters are known primary pollutants that directly affect plant physiology and human or indirectly cause harm, visible damage, and discomfort living organisms and environment through soil acidification (Das and Prasad, 2010; Jahan *et al.*, 2016; Bharti *et al.,* 2017). Moreover, pollutants in combination have effect in reduction of regional ecological condition which become huge threat to both the environment and health of the living organisms (Krishna and Lavanya, 2014; Kaur and Nagpal, 2017). Among the many identified air pollutants, dust from quarry and stone-mining sites, demographic pressure and overexploitation of open spaces have been implicated to contain suspended particulates like; plant pollen, hairs, fibers, burnt meteorite particles which can affect stomatal size and absorption ability of the foliar surfaces (Sharma and Roy, 1999).

Quarrying is a surface excavation for stone extraction associated with pollutions, damages to biodiversity and habitat destruction (Ogbonnaya and Phil-Eze, 2020). Though an economic activity, the suspended particles from its activities like excavations, stone loading and unloading come with notable negative environmental and health issues due to emitted particles (Saha and Padhy, 2011; Ogbonna *et al.,* 2018; Ekpa *et al.,* 2022). Dust is an important abiotic and stress factor which plays vital roles in determination of the physiological and biochemical activities in an organism. Dust deposition on the plant surface affects its overall development such as anatomical and morphological changes or reduces its productivity due to the poor chloroplast content and stomatal blockage (Shamaila, *et al.,* 2015; Shukla *et al.,* 2019). However, plant reactions to the impacts of dust pollution varies depending on the leaf morphology and sources of dust pollutions such as soil suspension, running vehicles, unpaved road, volcanoes, factorial emissions as well as stone-mining activities (Kameswaran *et al.,* 2019; Ogbonna *et al.,* 2020). Plants found in and near quarry and stone-mining sites are mostly affected due to their direct exposure to concentrated pollutants as the first receptors. Generally, dust pollution has been reported to have effects on metabolic process in plants such as photosynthetic activities, mitochondrial, respiration and stomatal clogging of plants (Ogbonna *et al.,* 2020), whereas dust pollution associated with stone-mining is accompanied with morphological and biochemical changes in plant, as shown in leaves and cuticles abrasion, leaves necrosis, chlorosis, retarded growth, stomatal closure, especially at long term deposition (Mahecha *et al.,* 2013; Kameswaran *et al.,* 2019). The aim of this was to assess the impact of artisanal stone-mining on foliar parameters and air pollution tolerance indices of five plants commonly growing in and around a stone-mining site at Eziani, Nsukka, Nigeria.

MATERIALS AND METHODS

Description of study area

Eziani is a town within Nsukka Local Government Area of Enugu State, Nigeria and found between 6˚49'30''N and 6˚50'30''N and longitudes latitudes 7˚19'30''E and 7˚21'30''E (Fig 1). The area has 208 mm mean annual rainfall concentrated in eight months of the rainy seasons from March to October. The topography is sloppy and hilly, and the vegetation type is within the derived savanna belt. The soil type is fine sand mixed with builders' choice gravels which promote the artisanal stone-mining activities. The suspended particles generated from surface excavations, sand and stone sieving, loading and unloading and vehicular road dust contributed to the stone-mining dust pollution deposited on the leaves in and around the study site.

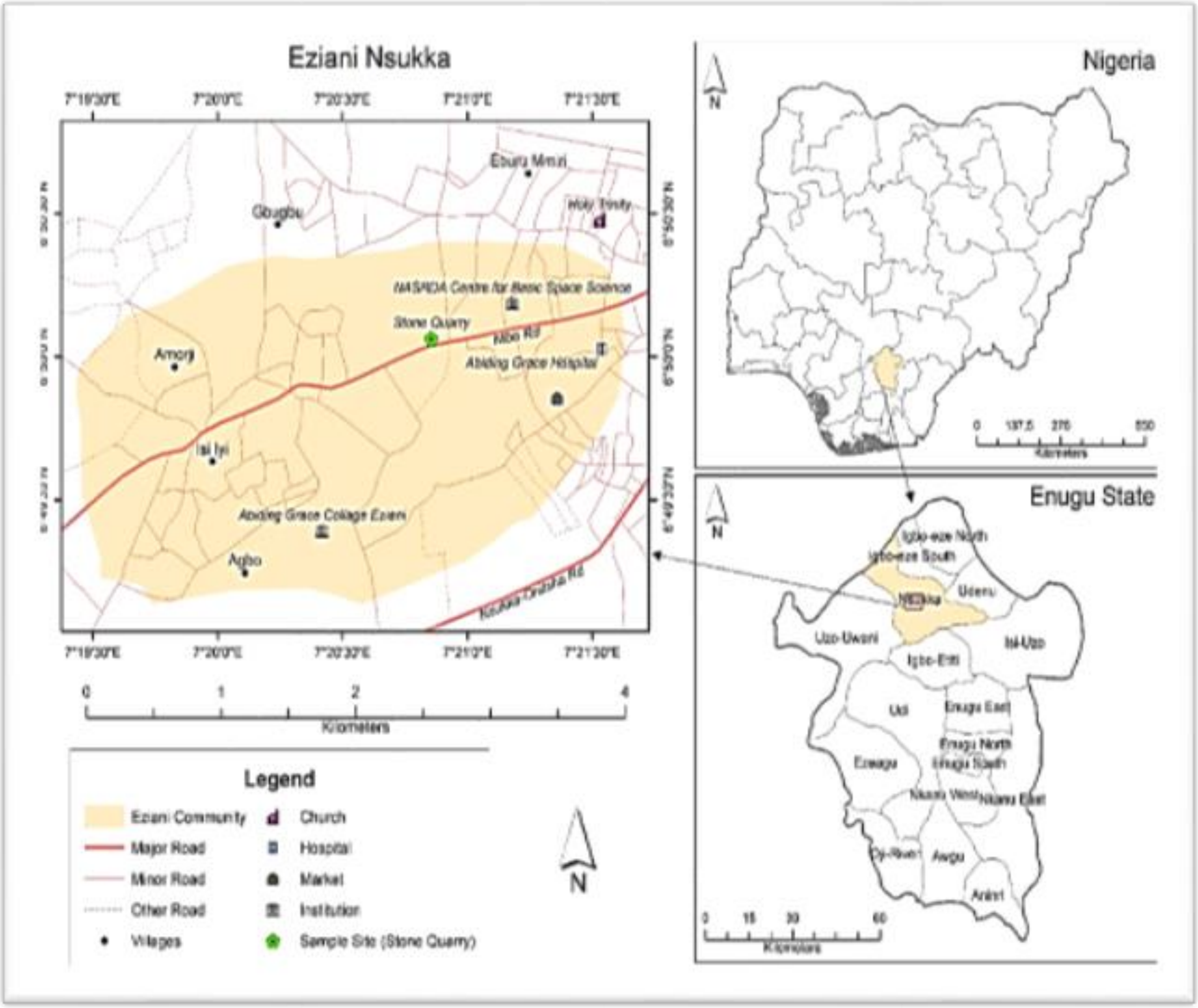


Figure 1. Map showing study area. (Source: Geographic Information System (GIS) Laboratory, Department of Geography, University of Nigeria, Nsukka)

Collection of plant samples

Five plant species were selected based on dominant and commonly identified plants growing in the stone-mining site of Eziani and University of Nigeria, Botanic Garden, the control. The control plants were obtained 7 km away from the study site. The plants include: *Annona senegalensis, Bridelia ferruginea, Ficus capensis, Nauclea latifolia and Protea madiensis.* Exposed fresh leaves at lower branches were collected on three different visits to the study site in the morning from 9 am to 11 am and during the month of January, 2022, when dust pollution was at its peak. The samples were labelled and analysis of dust load, leaf size, foliar epidermal characters and biochemical parameters were done immediately in the laboratory. Stomata analysis was carried out in five replicates while biochemical tests were done in triplicates.

Measurement of dust load

Dust accumulated on the leaves were measured using the methods described by Pandit *et al.,* 2017. This was done by first recording the initial weight (iw) of the leaf samples with dust on an electronic scale, followed by brushing off the dust accumulated on the leaf surface and reweighing of the leaf samples without dust to get the final weight (fw). Amount of the accumulated dust in mg is the difference between fw and iw while dust accumulation potential per unit area (cm^2) is the product of the measurement of the leaf area (cm^2) of the samples calculated as:

Leaf area (A) = L x W, then Dust accumulation (mg/cm^2) = fw – iw ÷ A

Where A= leaf area, L= leaf length, W= leaf width, fw= final weight and iw= initial weight of leaf.

Leaf morphology and Foliar analysis

The clearing method of Nwafor *et al*. (2019) was used for the preparation of adaxial (upper) and abaxial (lower) leaf surfaces of the foliar epidermis by soaking the leaf samples in commercial bleach "Jik" (3.5% sodium hypochlorite) for eighteen hours. Scrapped epidermal strips of the leaves were kept on a clean slide, stained with safranin and covered with a cover slip. The slides were mounted and viewed under a light microscope (model-No.271961-Japan) at x400 magnifications and photomicrographs were taken with a Moticam Camera 2.0 image system software fitted to the microscope. The epidermal cell types, stomata types, sizes and density were assessed and recorded.

Determination of biochemical parameters and APTI

Ascorbic acid content (mg/g) **-** used spectrophotometric procedure of Satpute and Bhalerao 2017 by extracting a gram (1 g) of the fresh leaf in 4 ml of oxalic acid-EDTA solution. Then in a test-tube, the extract (g), orthophosphoric acid (1 ml), 1 ml of 5% tetraoxosulphate (vi) acid, 2 ml of ammonium molybdate and 3 ml of water were mixed and allowed to settle for 15 minutes. The absorbance was measured at 760 nm and the concentration of ascorbic acid of the samples was calculated from the standard curve.

Leaf extract pH – The measurement method of Sahu *et al.* (2020) was used by homogenizing the leaf extract electrometrically with deionized water (10 ml) and reading for pH with digital pH meter from the filtrate.

Relative water content (RWC) – This was carried using the method of Singh (1977) by measuring the fresh weight (FW) of the samples, submerging them in distilled water over night. It was then dried and reweighed to take the turgid weight (TW), then later, dried for 48 hours in hot air oven at 70˚C and reweighed again to get dry weight (DW). RW calculation used the formula:

$$RWC = [(FW - DW) / (TW - DW)] \times 100$$

Total chlorophyll (TC) – This followed the procedure described by Arnon (1949) by extracting 3g of fresh leaves with 10 ml of 80% acetone for 15 minutes, decanting the liquid part, centrifuging at 2,500 rpm for 3 mins and measuring the absorbance spectrophotometrically at 645nm and 663nm. Total Chlorophyll (TC) was calculated using the formula below:

TC = chlorophyll a + Chlorophyll b mg/g

Where chlorophyll a = 12-7 (D643) – 2.69 (D645) x Vml mg/g 1000w,

chlorophyll b = 22-9 (D645) – 24.68 (D665) x Vml mg/g 1000w,

D = wavelength nm absorbance of the extract, V = Volume of total chlorophyll solution (ml) and W = Extracted sample weight (g).

Air pollution tolerance indices (APTI) of the plants were calculated from biochemical parameters according to Jaya *et al.,* 2017 using the following expression:

$$APTI = \frac{A(T+P) + R}{10}$$

Where: A = Ascorbic acid content, T = Total chlorophyll (mg/g), P = Leaf extract pH and R = Relative water content of leaf (%).

Statistical analysis

Data collected were subjected to One-way Analysis of Variance done using statistical package for social sciences (SPSS) version 2 0 to check for the significance among the five samples and Duncan multiple.

RESULTS AND DISCUSSION

Morphological Examination, Leaf sizes and dust accumulation of the study plants.

Results of the leaf shapes and forms in Table 1 showed entire margin except serrated margin in *F. capensis*. Leaf shapes ranged from broad elliptic in *N. latifolia,* elongated ovate in *P. madiensis,* oblong to ovate in *A. senegalensis*, obovate in *B. ferruginea* to ovate in *F. capensis.* Differences on the leaf apex, margin and shape obtained could be inherent growth habit. The variations observed in our study are in agreement with those reported on leaf morphology of some species of family Euphobiaceace and different *Ficus* species respectively (Ogbonna *et al.,* 2018 and Adamu *et al.,* 2021). Liu *et al.,* (2019) attributed differences in leaf morphology to adaptive features and the ability to withstand environmental factors such as serrated leaf margins which help to reduce transpiration rate.

Quantitative measurements showed significant variations in the amount of dust accumulated and leaf sizes (Table 2). At both sites, *N. latifolia* and *A. senegalensis* had the largest leaf area while *B. ferruginea* had the smallest leaf area. At the control site, *N. latifolia* and *A. senegalensis* had 175.39 ± 77.18 cm^2 and 140.18 ± 10. 09 cm^2 respectively while *B. ferruginea* had 91.63 ± 8.54 cm^2. Whereas, at the polluted site, *N. latifolia* and *A. senegalensis* had 162.22 ± 21.83 cm^2 and 123.74 ± 11.43 cm^2 respectively while *B. ferruginea* had 84.81 ± 4.85 cm^2, the smallest leaf area. Dust accumulation potentials on the leaves differed significantly ($p \leq 0.05$) across the plants. At stone-mining site *N. latifolia* accumulated highest amount of dust, 811.93 ± 21.11mg and *P. madiensis* leaves had the least, 485.24 ± 19.92 mg while *A. senegalensis* had highest dust accumulation, 411.10 ± 58.72 mg and *P. madiensis* had the least, 285.19 ± 21.12 mg at control site.

Variations on dust accumulation potentials on leaves depend on many factors relating to the nature of the leaf such as the height, canopy, texture, size, roughness or smoothness of the blade, orientation, locations, petioles length, seasons, nearness to the source of dust, wind direction, air current and speed. Walia *et al.* (2019) attributed leaf dust accumulation capacity to leaf nature like leaf size, texture, orientation while Ogbonna *et al.* (2020) attributed dust load potentials of plants to effects of location. Results showed that *N. latifolia* leaves accumulated the highest amount of dust while those of *B. ferruginea* accumulated the least amount. This can be corroborated with the fact that *N. latifolia* has the largest leaf surface area and agreed with previous findings reported by Ogbonna *et al.* (2018).

Table 1: Leaf morphological features of the selected plants.

Parameters	*Annona senegalensis*	*Nauclea latifolia*	*Bridelia ferruginea*	*Ficus capensis*	*Protea madensis*
Leaf	has oblong to ovate shape, entire margin with notched apex, lobed base	broad elliptic shape, entire margin with short acuminate apex and subcordate base	Obovate shape, entire margin with obtuse apex and rounded base	Ovate to elliptic shape, serrated margin with acuminate apex and cordate base	Elongated ovate shape, entire margin with blurred acumen and cordate base

Table 2: Leaf sizes and dust load of the plants at polluted stone-mining and control site.

Plant species	Leaf area (cm^2)		Dust load (mg)	
	Polluted	Control	Polluted	Control
A. senegalensis	123.74 ± 11.43^b	140.18 ± 10.09^b	726.21 ± 43.72^b	411.10 ± 58.72^a
B. ferruginea	84.81 ± 4.85^d	91.63 ± 8.54^d	693.82 ± 72.44^d	399.47 ± 36.62^b
F. capensis	116.24 ± 10.83^c	$120.15 \pm 43\ 68^c$	692.23 ± 40.02^d	340.14 ± 21.00^d
N. latifolia	162.22 ± 21.83^a	175.39 ± 77.18^a	811.93 ± 21.11^a	410.44 ± 18.01^a
P. madiensis	119.73 ± 9.65^c	124.92 ± 38.12^c	485.24 ± 19.92^c	285.19 ± 21.12^c

Values expressed as mean ± standard error of mean of five replicate experiments. Means with different letters as superscripts are significantly different at $p \leq 0.05$

Foliar studies

The epidermal images from photomicrographic study are summarized in Plates 1-5 while stomata characters of the studied plants are presented in Table 3. The foliar studies revealed differences in epidermal cells and stomatal types. The leaf epidermal cells are mostly polygonal shaped on abaxial surface inter-mixed with irregular adaxial part. The stomata distribution in all plants showed hypostomatic type in the lower side of the leaf surface except amphistomatic type found in *N. latifolia* where stomata appeared on lower and upper sides of the leaf.

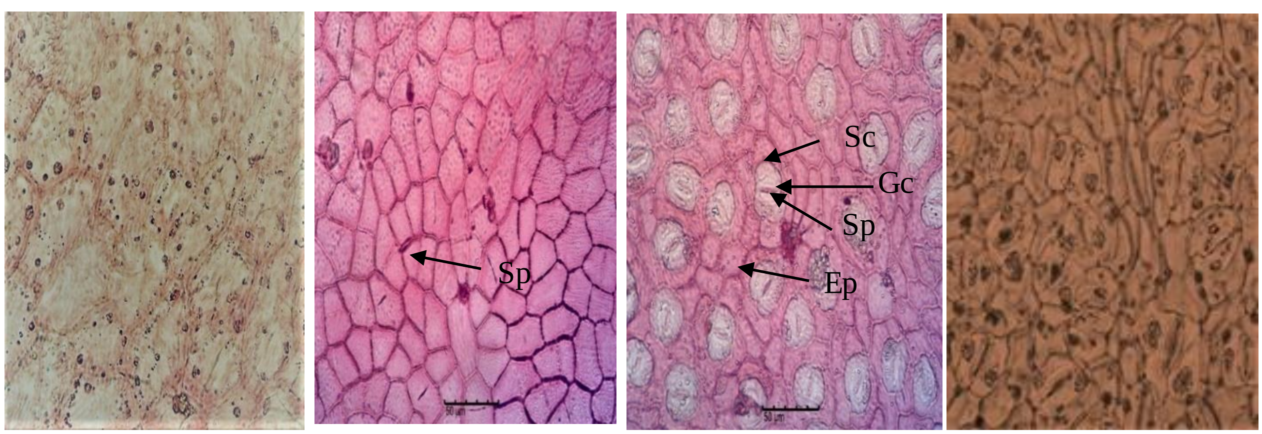
The stomata type in *N. latifolia* was paracytic (in which the subsidiary cells were two and appeared parallel to the long axis of the guard cell wall) with polygonal epidermal cell and unbent anticlinal cell walls on both surfaces (Plates 1a-d). Also, *P. madiensis* was polygonal with unbent anticlinal cell walls on both surfaces and anomocytic stomata (in which there were no subsidiary cells that differed from other epidermal cells) (Plates 2a-d). Paracytic stomatal type was found in *A. senegalensis* with polygonal epidermal cells, unbent anticlinal cell wall on adaxial (upper) surface (Plates 3a and b) and curved to wavy on abaxial (lower) surface (Plates 3c and d). In *B. ferruginea* the epidermal cell types had irregular shape with unbent to curved anticlinal cell walls pattern on both surfaces (Plates 4a-b) and anisocytic stomatal type in abaxial surface. *F. capensis* had polygonal shape, unbent anticlinal cell pattern in adaxial surface and actinocytic stomatal type mainly in abaxial surfaces (Plates 5a-d). Cell shape and cell wall pattern are two characters that vary considerably within plants (Aworinde *et al.,* 2009**).** Polygonal shaped epidermal cell was reported in *A. senegalensis* in both abaxial and adaxial sides (Adeniran 2020) and in abaxial surface of *B. ferruginea* (Aworinde *et al.*, 2009) and *N. latifolia* (Ogbonna *et al.,* 2018) similar to the present findings. Aworinde *et al.* (2009) also observed isodiametric shaped epidermal cell on the adaxial surface of *B. ferruginea* which differed from this study.

Mean stomata parameters such as size of the stomata length, width and area seemed reduced but stomata number and density increased significantly in polluted stone-mining plants when compared to the controls. In both study sites, *P. madiensis* was significantly the highest in all the parameters, *F. capensis* produced the lowest mean stomata number and density while *B. ferruginea* had the least in the mean stomata length, width and area. Results from the leaf epidermal studies revealed that dust pollution from the study site affected the physiology of the epidermal cells and stomata. This corroborates with previous findings on foliar distortions of plants collected from dust-polluted sites (Ogbonna *et al.,* 2018; Ogbonna *et al.,* 2020).

Table 3: Stomata parameters of upper leaf surface of the studied plants

Parameters	Stomata number (pfv)		Stomata density (mm^{-2})		Stomata length (µm)		Stomata width (µm)		Stomata area (µm^2)	
	Polluted	Control	Polluted	Control	Polluted	Control	Polluted	Control	Polluted	Control
A. senegalensis	17.75 ± 0.48*	15.25 ± 0.25	104.41 ± 2.82*	89.71 ± 1.47	23.26 ± 1.39	27.34 ± 0.94*	12.25 ± 0.35	12.89 ± 0.23^{NS}	284.52 ± 16.04	352.88 ± 15.75*
B. ferruginea	20.50 ± 0.29*	17.00 ± 0.41	120.59 ± 1.69*	100.00 ± 2.40	17.59 ± 0.52	19.82 ± 0.18*	11.73 ± 0.43	13.11 ± 0.17*	230.64 ± 7.18	259.79 ± 2.11*
F. capensis	14.25 ± 0.48*	11.75 ± 0.25	83.82 ± 2.82*	69.12 ± 1.47	26.60 ± 0.89	27.99 ± 0.71^{NS}	17.67 ± 0.39	22.42 ± 0.59*	471.01 ± 25.69	627.45 ± 21.94*
N. latifolia	23.75 ± 0.25*	20.25 ± 0.48	139.71 ± 1.47*	119.12 ± 2.82	22.67 ± 0.95	28.10 ± 0.26*	12.01 ± 0.49	17.07 ± 0.15*	273.68 ± 22.29	479.68 ± 7.65*
P. madiensis	26.75 ± 0.48*	20.75 ± 0.25	157.35 ± 2.82*	122.06 ± 1.47	43.16 ± 0.71	52.65 ± 1.90*	23.99 ± 0.38	30.17 ± 0.84*	1034.54 ± 7.08	1587.74 ± 64.60*

Values expressed as mean ± standard error of mean of 5 replicate data. *Significantly higher at $p \leq 0.05$; ^{NS} Not significantly higher at $p \leq 0.05$



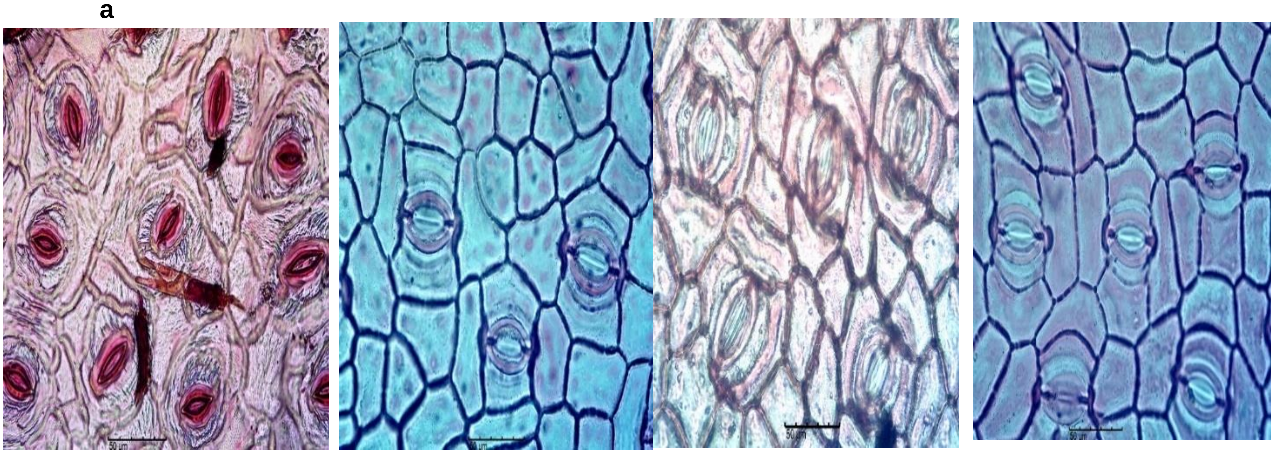
a

b c d

Plates: 1a – d: *N. latifolia*

Key: Sp = stomatal pore; Gc = guard cell; Sc = subsidiary cell; Ep – epidermal cell.

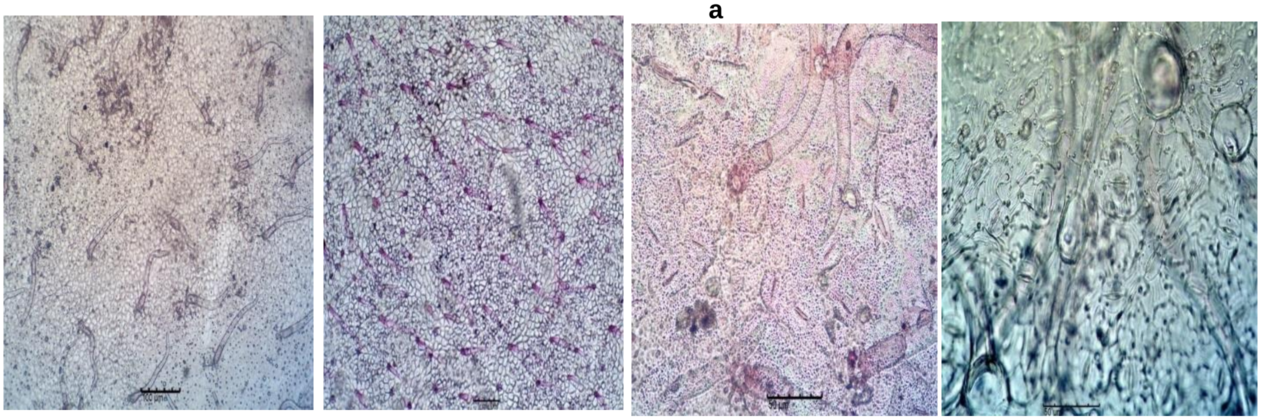
a



b c d

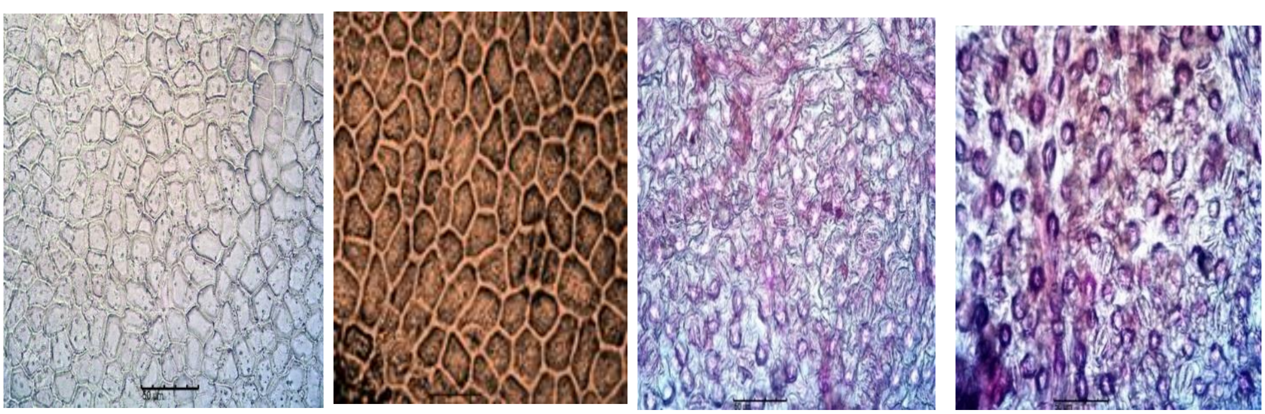
Plates 2a – d: *P. madiensis*

a



b c d

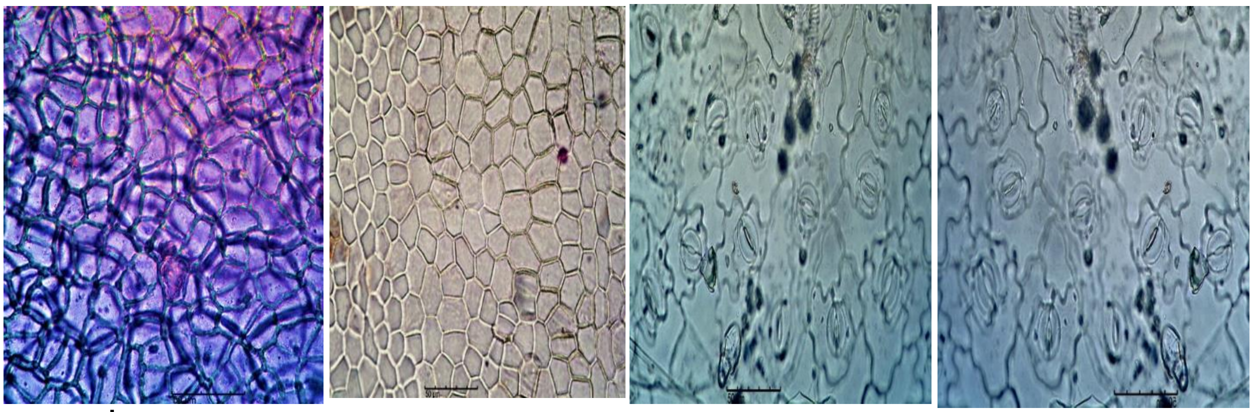
Plates 3a – d: *A. senegalensis*



a b c d

Plates 4a – d: *B. ferruginea*

a b c



d

Plates 5a – d: *F. capensis*

Key: Plates a – d = The leaf epidermal cells; a & b = Adaxial surfaces; c & d = Abaxial surfaces; a and c = Study areas; b and d = Controls;

Biochemical studies

Results of the biochemical properties and air pollution tolerance index are presented on Table 4. Total chlorophyll content varied significantly from 0.24 to 1.77 mg/g and was higher in *N. latifolia* and low in *F. capensis*. This was considered useful in plant photosynthetic activities, biomass growth and productivity. Bharti *et al.* (2017) described chlorophyll content as an important index to assess impact of dust pollution on photosynthetic rate of leaves. Decrease in chlorophyll content is an indication of poor photosynthetic rate, leaf injury or increased chlorophyllase enzyme activity resulting from high dust load on the leaves which affected stomata opening and closing mechanism (Leghari *et al.,* 2014).

Mean ascorbic acid ranged from 8.62±0.48 in *P. madiensis* to 15.28±0.02 in *A. senegalensis* at the polluted site and 8.79±0.03 in *P. madiensis* to 14.97±0.01 in *A. senegalensis* at the control site. It is a free radical scavenger that provides plants protection to cope with stress conditions resulting from photo oxidation process of SO_2 (Shrestha *et al*., 2021). High ascorbic acid in polluted leaves indicate tolerant ability towards air pollution stress and a good defense signal in plants (Pandey *et al.,* 2015) whereas its low content signifies sensitive towards pollutants and a mark for physiological alteration before appearance of physical injury symptoms (Tripathi *et al.,* 2009). Moreover, Ascorbic acid is a recognized index in photosynthetic carbon fixation in plants (Nwadinigwe, 2014), useful in activating many physiological conditions like cell wall synthesis and formed a multiplication factor in APTI derivation formula. Our finding suggests that *A. senegalensis, F. capensis and N. latifolia* in this order can be considered as dust pollutant tolerant species, and this is in agreement with the findings of Swami and Chauhan (2015) who reported that plants with increased ascorbic acid content in polluted environments are regarded as pollution tolerant species.

Relative water content had significantly varied from 52.56±0.19 in *B. ferruginea* to 75.57±4.22 in *A. senegalensis* at the polluted site and 58.29±0.04 in *B. ferruginea* to 77.33±1.32 in *P. madiensis* at the control site. This is a useful determinant of transpiration rate in plant leaves under stress conditions and it affects early aging, mineral and water loss in plant leaves (Tsega and Prasad, 2014; Ogunkunle et al., 2015). It offers physiological balance during high water vapour and prolonged water loss conditions in plants, (Joshi and Swami, 2007). Presently, except in *F.capensis,* relative water content is reduced significantly in all other plants compared to control plants. This observed reduction agrees with an earlier report which showed that a decrease in the relative water content of plants is an indication of the effect of pollution stress on transpiration rate in leaves (Swami *et al*., 2004). Also, in plants, increase and decrease in the levels of different parameters serve as an adaptation information of the plant to environmental conditions (Karmakar *et al.,* 2016).

The pH ranged from 5.25±0.10 in *F. capensis* to 7.30±0.10 in *N. latifolia.* Plant pH influences stomatal sensitivity because presence of acidic pollutants reduces pH more in the sensitive plants (Chouhan *et al.,* 2012). Thus, leaf pH provides information on pollution conditions of plants as a sensitivity indicator of air pollution. Our result showed that pH values are close to pH 7. Neutral or high pH signify more pollution-tolerance whereas low pH shows more susceptibility to pollution (Joshi *et al.,* 2016). This implies that polluted stone-mining plants are tolerant species, as their values are closer to pH 7.

Also, APTI ranged from 11.38 ± 0.07 in *B. ferruginea* to 17.14 ± 0.24 in *A. senegalensis* at the polluted site and 13.49±0.28 in *B. ferruginea* to 18.92 ± 0.24 in *A. senegalensis* as well. The significant highest and lowest APTI in both polluted and control sites were recorded in *A. senegalensis* and *B. ferruginea* respectively. The tolerance index in both sites was observed to be in increasing order of: *A. senegalensis* > *F. capensis* > *N. latifolia* > *P. madiensis* > *B. ferruginea.* Also, by using the three categories of APTI values: sensitive (APTI values ≤ 11), intermediate (12 to 16 APTI values range) and tolerant (values ≥ 17) species (Padmavathi *et al.,* 2013; Bharti *et al.,* 2017), present results showed that polluted plants were intermediate tolerant plants with *A. senegalensis* (17.14±0.24) being the most tolerant to air pollution, followed by *F. capensis* (14.76±0.12). APTI of 17.14 suggests that *A. senegalensis* should be grown close to any dust polluted areas. Comparatively, polluted plants produced low tolerance index than the controls because they may have been subjected to prolonged dust particles. Therefore, plants with high APTI value serve as pollutant absorbers which mitigate pollution while those with lower values serve as bio-monitors.

Table 4: The biochemical parameters and APTI of polluted stone-mining and control plants.

Plant species	TCH mg/g	AA (mg/g)	pH	RWC (%)	APTI	TCH mg/g	AA mg/g	pH	RWC (%)	APTI
	Polluted					Control				
A. senegalensis	0.37± 0.05	15.28 ±0.02	5.90± 0.1	75.57 ±4.22	17.14 ±0.24	0.65± 0.19*	14.97± 0.01 ^{NS}	6.85± 0.05*	76.92± 0.04*	18.92± 0.24*
B. ferruginea	0.56 ± 0.01	9.41 ± 0.06	5.95 ± 0.05	52.56 ±0.19	11.38 ± 0.07	1.26 ± 0.03 ^{NS}	9.51 ±0.02 ^{NS}	6.80 ±0.30 *	58.29± 0.04*	13.49 ±0.28*
F. capensis	0.24± 0.04	14.52 ±0.05*	5.25± 0.1	67.86 ±0.04*	14.76 ±0.12	1.52± 0.03*	11.42± 0.01	7.25± 0.05*	63.28± 0.16	16.34± 0.09*
N. latifolia	1.39± 0.23	12.40 ±0.04*	5.70± 0.00	58.38 ±0.02	14.63 ±0.17	1.77± 0.19*	10.16± 0.02	7.30± 0.10*	75.73± 0.01*	16.79± 0.35*
P. madiensis	1.25± 0.01	8.62± 0.48	5.40± 0.00	73.17 ±0.28	13.05 ±0.14	1.68± 0.19*	8.79±0.03 ^{NS}	7.00± 0.20*	77.33± 1.32*	15.34± 0.04*

Values expressed as mean ± standard error of mean of 5 replicate data. *Significantly higher at p ≤0.05; ^{NS} Not significantly higher at p ≤0.05

CONCLUSION

This study evaluated foliar parameters and biochemical properties of five plants growing in and around stone-mining site in order to assess the impact of dust on them and their tolerance to the pollution. Dust load observed on the leaves gave rise to significant distortion and deformation in the epidermal and guard cells compared to the control leaves. Significant reductions in some stomata parameters are indication of alteration due to dust. Foliar studies showed that stomata parameters of *F. capensis* and *B. ferruginea* were the most reduced and destroyed. Differences were also observed in the APTI from biochemical properties assessment. Plants had intermediate tolerance to dust pollution with *A. senegalensis* (17.14±0.24) being the most tolerant to air pollution. APTI values from polluted plants were lower than the control plants. With

APTI mean of 17.14 together with less foliar changes and destruction when compared with the control suggests that *Annona senegalensis* can thrive in dust polluted areas.

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Declaration of competing interest

Authors have declared that no conflict of interests exist regarding this publication.

Author contribution

AAN and NFI designed the study, procured the plant specimens, did the laboratory experiments, performed the statistical analysis and helped in the revision of the manuscript. OCB and OHC wrote abstract, managed the literature and the references. ALN and IU wrote the protocol and helped in discussion and editing of the manuscripts. All authors read and approved the final version of the manuscript.

REFERENCES

Adamu, F.U., Abubakar, B.Y. and Musa, A. O. (2021). Morphological Characteristics of Different Ficus Species Found in Samaru-Zaria, Nigeria. *Dutse Journal of Pure and Applied Science,* **7**(3): 176–83.

Adeniran, S.A., Kadiri, A.B. and Olowokudejo, J. D. (2020). Taxonomic significance of some leaf anatomical features of the species of *Annona* l. (Annonaceae) from Nigeria. *Ife Journal of Science,* **22**(1): 101–112.

Agbaire, P.O. and Esiefarienrhe, E. (2009). Pollution tolerance indices (APTI) of some plants around Otorogun Gas Plant in Delta State, Nigeria. *Journal of applied Science and Environmental Management,* **13**(1): 11–14.

Arnon, D.I. (1949). Copper Enzymes in isolated chloroplasts polyphenol oxidase in *Beta vulgaris*. *Plant Physiology*, **24** (1): 1–15.

Aworinde, D.O., Nwoye, D.U., Jayeola, A.A., Olagoke, A.O. and Ogundele, A.A. (2009). Taxonomic Significance of Foliar Epidermis in Some Members of Euphorbiaceae Family in Nigeria. *Research Journal of Botany,* **4**: 17–28.

Bharti, S.K., Trivedi, A. and Kumar, N.(2018). Air pollution tolerance index of plants growing near an industrial site. *Urban Climate,* **24**:820-829.

Chouhan, A., Igbal, S., Maheshwari, R.S. and Bafna, A. (2012). A study of air pollution tolerance index of plants growing in Pithampur industrial area sector 1, 2 and 3. *Research Journal of Recent Science,* **1**: 172– 177.

Das, S. and Prasad, P. (2010). Seasonal variation in air pollution tolerance indices and selection of plant species for industrial area of Rourkela. *Indian Journal of Environmental Protection,* **30**(12): 978 – 988.

Ekpa, I.D., Laniyan, D.G., Agbor, C.N., Ben, U.C. and Okon, J.E. (2022). Assessment of air pollution from quarry activities on agriculture and plant biodiversity in South-Eastern Nigeria. *Research Square.*

Jahan, S., Falah, S., Ujah, H. and Rauf, N. (2016). Antioxidant enzyme status and reproductive health of adult male workers exposed to brick kiln pollutants in Pakistan. *Environmental Science Pollution Research,* **23**: 12932-12940.

Jaya, P.H. and Mukesh, K.C. (2017). Air pollution tolerance index of some selected gymnosperm species along the road side of Kathmandu Valley, Nepal. Ecoprint: *An International Journal of Ecology,* **24**: 13-19.

Joshi, N., Joshi, A. and Bist, B. (2016). Air pollution tolerance index of some tree species from the industrial area of Tarapur. *International Journal of Life Sciences,* **2**(2): 173 -182.

Joshi, P. C. and Swami, A. (2007). Physiological responses of some tree species under roadside automobile pollution stress around city of Haridwar, India. *Environmentalist,* **27**: 365 -374.

Kameswaran, S. Gunavathi, Y. and Krishna, P. G. (2019). Dust pollution and its influence on vegetation - A critical analysis. *Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemicals,* **5**(1): 341-363.

Karmakar, D., Malik, N. and Padh, P. K. (2016). Effects of industrial air pollution on biochemical parameters of *Shorea robusta* and *Acacia auriculiformis*. *Research Journal of Recent Sciences,* **5**(4): 29– 33.

Kaur, M. and Nagpal, A.K. (2017). Evaluation of air pollution tolerance index and anticipated performance index of plants and their application in development of green space along the urban areas. *Environmental Science and Pollution Research*, **24**: 18881–18895.

Krishna V.M. and Lavanya, K. (2014). Air pollution tolerance index of plants, a comparative study. *International Journal Pharmacy and pharmaceutical Sciences,* **6**(5): 320 – 324.

Leghari, S.K., Zaidi, M.A., Sarangzai, A.M., Faheem, M., Shawani, G.R. and Ali, W. (2014). Effect of road side dust pollution on the growth and total chlorophyll contents in *Vitas vinifera* L. (grape). *African Journal of Biotechnology*, **13**(11): 1237–1242.

Liu C., Li. Y. and Nianpeng, I. (2019). Variation in leaf morphological, stomatal and anatomical traits and their relationships. *Scientific reports,* **9**(1): 5803–5813.

Mahecha, G.S., Bamniya, B.R., Nair, N. and Saini, D. (2013). Air pollution tolerance index of certain plant species: A study of Madri Industrial area, Udaipur (Rajasthan), India. *International Journal of Innovative Research Science Engineering and Technology,* **2**(12): 7927–7929.

Nwadinigwe, A. O. (2014). Air Pollution Tolerance Indices of some plants around Ama industrial complex in Enugu State, Nigeria. *African Journal of Biotechnology,* **13**(11): 1231–1236.

Nwafor, F. I., Nwosu, M.O. and Nwafor, A. Z. (2019). Taxonomic and ecological significance of foliar epidermal characters in four taxa of *Mussaenda* L. (Rubiaceae) in Nigeria. *Annual Research and Review in Biology*, **32**(5): 1–12.

Ogbonnaya, J.E. and Phil-Eze, P.O. (2020). Challenges of quarry activities for sustainable quality water resources in Abakaliki and Environs. *Journal of Geography and Meteorology and Environment*. **3**:1-13.

Ogbonna, C.E., Nwafor, F.I. and Ogbonnaya, O.O. (2020). Dust Accumulation, Heavy Metal Content and Stomata Morphology of Some Medicinal Plants at Rock Quarrying Locations at Lokpaukwu, Nigeria. *International Journal of Environment and Climate Change,* **10**(12): 540–549.

Ogbonna, C.E., Nwafor, F.I., Ugbogu, E.A. and Nwazue, K. (2018). Assessment of foliar parameters and their air pollution tolerance of broad leaves in Ugwuele Quarry site, Uturu, Nigeria. *Applied Ecology and Environmental Science,* **6**(2): 48–56.

Ogunkunle, C.O., Suleiman, L.B., Oyedeji, S., Awotoye, O.O. and Fatoba, P.O. (2015). Assessing the air pollution tolerance index and anticipated performance index of some tree species for biomonitoring environmental health. *Agroforestry systems*, **89**: 447– 454.

Padmavathi, P., Cherukuri, J. and Reddy, M.A. (2013). Impact of air pollution on crops in the vicinity of a power plant: A case study. *Int. J. Eng. Res. Technol*, **2**(12): 3641–3651.

Pandey, A. K., Pandey, M., Mohan, S., Tiwary, S. M. and Tripathi, B. D. (2015). Air pollution tolerance index and anticipated performance index of some plant species for development of urban forest. *Urban Forestry and Urban Greening,* **14**(4): 866 – 871.

Pandit, J., Sood, A., Bhardwaj, S.K. and Sharma, K.K. (2017). Seasonal variation of leaf dust accumulation and biochemical parameters of selected plant species alongside the national highway-7 in Sirmaur, India. *Current World Environment*, **12**(2): 421– 428.

Saha, D.C. and Padhy, P.K. (2011). Effects of Stone Crushing Industry on Shorea robusta and Medhuca indica foliage in

Lalpahari Forest. *Atmospheric Pollution Research,* **2**: 463– 476.

Sahu, C., Basti, S. and Sahu, S.K. (2020). Air pollution tolerance index (APTI) and expected performance index (EPI) of trees in Sambalpur town of India. *Springer Nature Applied Sciences,* **2**: 1327.

Shukla, S., Sharma, R.B. and Sahu, M. (2019). Dust pollution affect morphophysiological traits of plant *Mangifera indica* Linn. *International Journal of Botany*: **15** (1): 1-4.

Satpute, S.B. and Bhalerao, S.A. (2017). Assessment of air pollution tolerance index (APTI) and anticipated performance index (API) for designing green belt. *Research Journal of Chemical and Environmental Sciences,* **5**(1): 86–94.

Shamaila, Z., Wolfram, S., Yang, P., Xiaoning, Z., Hussein, O., Xiongkui, H. and Joachim, M. (2015). Effect of dust deposition on stomatal conductance and leaf temperature of cotton in Northwest China. *Water,* **7**: 116–131.

Sharma, S.C. and Roy, R.K. (1999). Bioremediation of urban environmental Pollution by ornamentals. *Journal of Environment Science Engineering,* **47**: 131–134.

Shrestha, S., Baral, B., Dhital, N. B. and Yang, H. (2021). Assessing air pollution tolerance of plant species in vegetation traffic barriers in Kathmandu Valley, Nepal. *Sustainable Environment Research*, **31**(3): 1 – 9.

Singh, A. (1977). Practical Plant Physiology. Kalyari Publishers. New Delhi.

Swami, A., Bhatt, D. and Joshi, P.C. (2004). Effects of automobile pollution on Sal (*Shorea robusta*) and Rohini (*Mallotus phillipinensis*) at Asarori, Dehradun. *Journal of Environmental Zoology,* **18**(1): 57–61.

Swami, A. and Chauhan, D. (2015). Impact of air pollution induced by automobile exhaust pollution on air pollution tolerance index (APTI) on few species of plants. *International Journal of Scientific Research*, **4**(3):342-343.

Tripathi, A., Tiwari, P.B., Mahima and Singh, D. (2009). Assessment of air pollution tolerance index of some trees in Moradabad city, India. *Journal of Environmental Biology*, **30**(4): 545-550.

Tsega, Y. C. and Prasad, A. D. (2014). Variation in air pollution tolerance index and anticipated performance index of roadside plants in Mysore, India. *Journal of Environmental Biology,* **35**: 185 – 190.

Walia K., Aggarwal R.K. and Bhardwaj, S.K. (2019). Leaf dust accumulation and its relationship with biochemical parameters of different plant species growing along national highway 22, India. *International Journal of Chemical Studies,* **7**(1): 1386–1390.